introduces some friction in the mechanism. However, the friction is completely eliminated by the control loop, up to the accuracy of the force sensor. The result in force control mode is a backlash-free, stick-free, and slip-free smooth motion at the end effector. A sensitive strain gauge force sensor is located right behind the end effector. Such strain gauge force sensors, (or load cells) are well known in the art, for example, the JR3 Sensors, the EBB Series Load Cell, or the LSP Series Load Cell, available from Transducer Techniques (Temecula, Calif.). By placing the force sensor adjacent to the end effector, the interaction force is measured as close to the human hand as possible to avoid distortion of the force signal and to optimize system performance. Exchangeable end effectors can be mounted to the force sensor to match the application.

[0114] Servo motors that drive the robot arm are well known to those in the art, and include, for example but are not limited to, the 815 BR or the 1525-BRS (Servo Dynamics Corp., Chatsworth, Calif.).

[0115] The control box contains electronics such as the computer, motor amplifiers, and an emergency circuit. The virtual model is rendered by a dedicated computer with a real-time operating system, such as VxWorks (Wind River Systems, Alameda Calif.), QNX, LynxOS, VRTX, pSOS, Windows-CE, Nucleus RTX, RT Linux, or the like, herein termed the haptic server. Such servers and operating systems are well known to those in the art. It runs at a fixed 2,500 Hz refresh rate. This frequency is high enough to guarantee a haptic quality for a smooth and realistic experience since it is approximately ten times higher than the maximal human discrepancy value (Burdea G. (1996) "Force and Touch Feedback for Virtual Reality" Wiley, New York, N.Y.). Finally, the PID motor control loop runs on the amplifiers at a 20 kHz pulse width modulated frequency.

[0116] It must be noted that other configurations of the haptics device are possible. **FIG. 7** shows one such example of a 3-D haptic device concept where the axes are fully independent. It is expected that many versions of the haptics device can be developed, accommodating the full performance envelope of force, velocity and position.

[0117] It is understood that for someone skilled in machine design arts many different ways can be found to drive an end effector in three or more degrees of freedom. Another example which is far more complex is a Stewart platform given in **FIG. 8**. This is used extensively in flight simulators to provide motion sensation to the pilots. The hexapod structure uses six actuators, and is thus capable of providing 6-DOF motion. In the system of the present invention the end effector and associated additional hardware may be mounted on the top platform.

[0118] End effectors may also be of different configurations dependent on the application and type. As mentioned before; specific protocols integrating wrist and/or hand functions may require unique and dedicated end effectors.

[0119] At least one position measurement device can be included in the system, a position measurment device such as a tracker, a potentiometer, or the like. The position measurement device can be fixedlyattached to any part of the system, however it is preferable to attach the position measurement device to or adjacent to a joint, a sensor, or the like so that the position of an element of the system can be accurately determined. In addition, several position measurement devices can be attached to different locations on the system in order to obtain an accurate estimate of the position of the entire system.

Extra-Skeletal Approach

[0120] In addition to end effector approaches, extra-skeletal robots can be designed to implement the same virtual mechanical environment to overcome gravity-induced dysfunction in upper extremity paresis following stroke, head trauma and spastic cerebral palsy. As long as such systems can provide the means to alter weight of the limb in the workspace of the arm and the ability to provide resistance to motion, if so desired, the neurorehabilitation concept discussed as part of this application can be realized.

Rehabilitation Software and Visual System

[0121] The rehabilitation software can allow for data collection of evaluation and training data. The quantitative evaluation software is developed to:

[0122] A: Determine any limitations in available torque combinations by performing ballistic reaching/retrieval arm movements in different directions while maintaining various levels of shoulder abduction torque. The protocol allows an operator to establish the severity of abnormal coupling(s) between shoulder/elbow torques as a function of limb support activity. The software can display sparks and/or provide a sound (indicating that the arm is touching the table) if subjects do not maintain an abduction level within 10% of the assigned torque value during reaching/retrieval movements.

[0123] B: Determine the maximal reaching workspace. Similar movements as in A) can be performed for different inclination angles of the virtual table to determine the maximal reaching workspace of the paretic arm. In the case that subjects are mildly impaired, the weight of the arm can be increased by simulating objects with increasing weight. The software can be developed to provide a quantitative measure of workspace for different percentages of active limb support.

[0124] The results provided by protocols A & B can be used to establish parameters for the training software. The software for the training protocols is similar to the software developed for the quantification and evaluation protocols allowing visual display and measurement of virtual planar surfaces and active support of the limb. In addition, this software can allow for a progressive increase of active support of the limb during subsequent training sessions.

[0125] An additional component in the training software can be to provide a subject the ability to strengthen the paretic limb while subjects move on a virtual plane supporting part of the weight of the arm. This can be realized by:

[0126] A) Ballistic reaching movements using predetermined targets on the virtual plane;

[0127] B) Reaching motions within an imposed viscous field on the virtual plane; and/or

[0128] C) Isokinetic reaching motions that limit the maximum movement velocity on the virtual plane.

[0129] The training software can include these options for research and clinical trials.